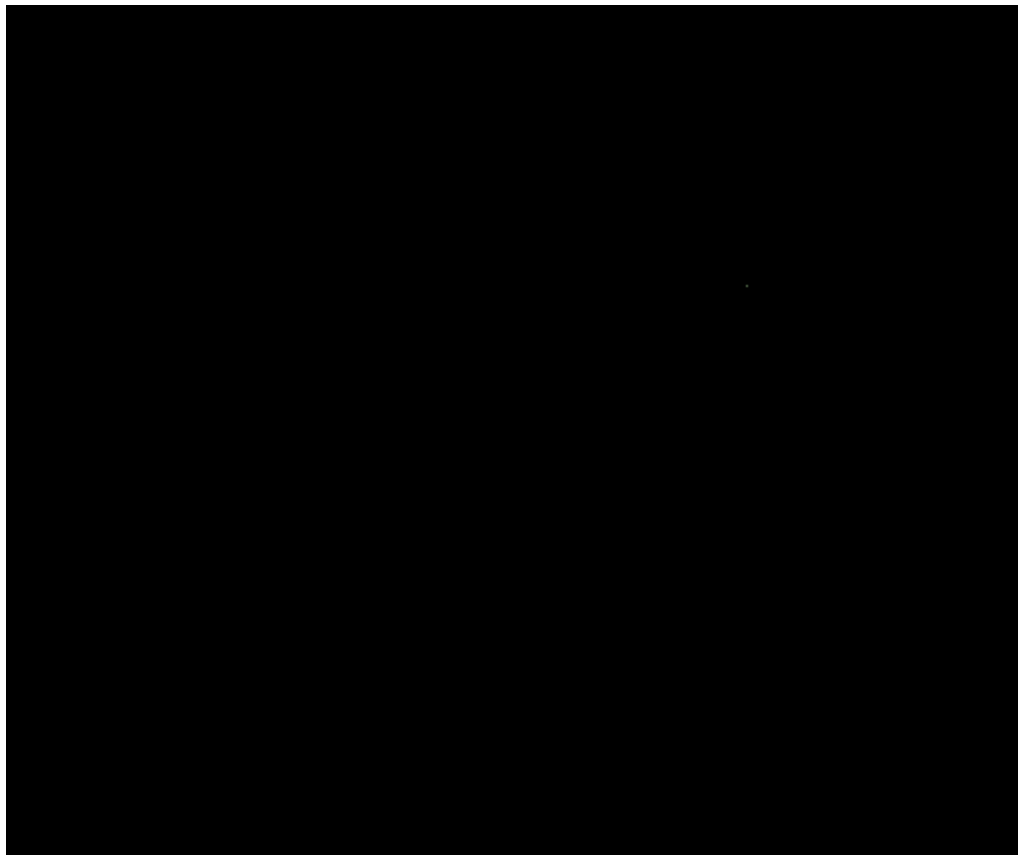
From Pixels to Regions: Hierarchical Segmentation Pre-Processing for Image Analysis

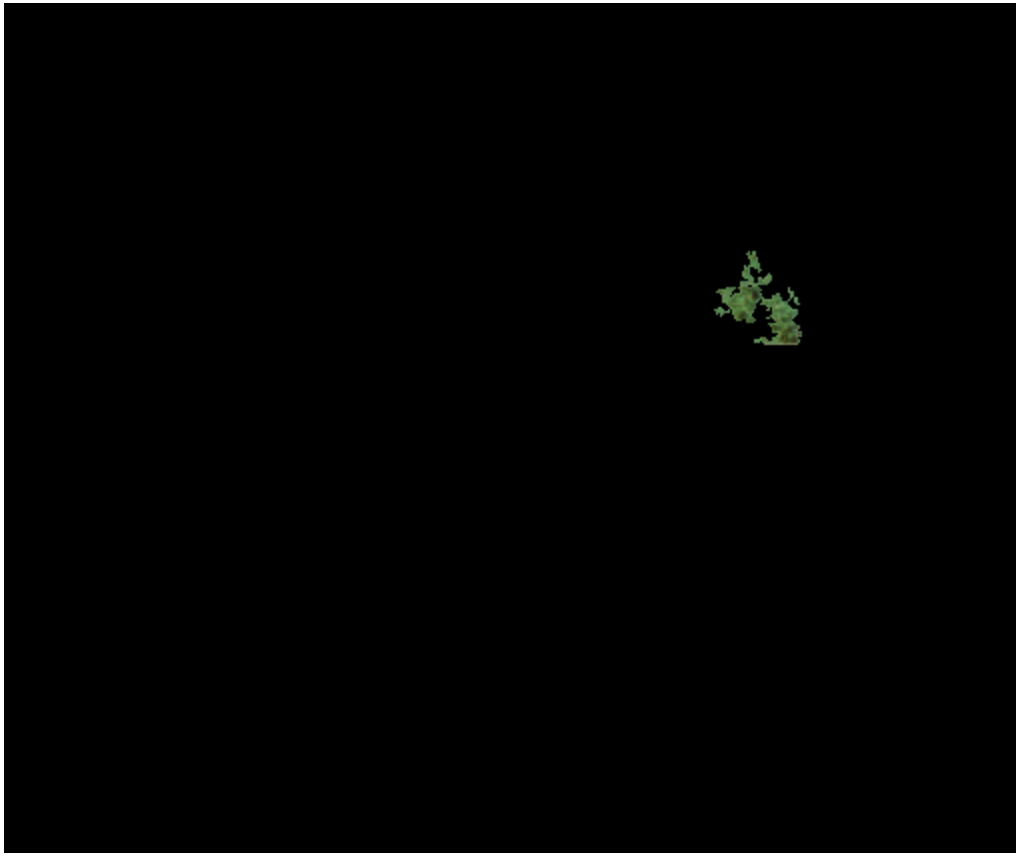
James C. Tilton
Mail Code 606.3*
NASA GSFC
Greenbelt, MD 20771
James.C.Tilton@nasa.gov

*Computational & Information Sciences and Technology Office (CISTO)

Goal: Transform Pixel-based Analysis to Region-based Analysis

- Pixel-based analysis makes decisions based on information available at pixel location (often multispectral or hyperspectral). Statistical or spectral matching techniques are often utilized.
- Region-based analysis adds information about a region object containing the pixel – e.g. texture and/or shape information.





What level of Segmentation Detail?

A problem with image segmentation based on region growing is - what is the appropriate amount of segmentation detail?

Solution 1: Try to find a universal threshold defining a single segmentation output.

Solution 2: Selectively output a set of segmentations at different levels of detail: a segmentation hierarchy.

What is a Segmentation Hierarchy?

A set of image segmentations that

i. consist of segmentations at different levels of detail, in which

ii. the coarser segmentations can be produced from merges of regions from the finer segmentations, and

iii. the region boundaries are maintained at the full image spatial resolution.

31 Region Segmentation

22 Region Segmentation

12 Region Segmentation

10 Region Segmentation

6 Region Segmentation

4 Region Segmentation

2 Region Segmentation

Ten level Hierarchical Boundary Map

Advantages of a Segmentation Hierarchy

- Image Analysis is transformed from pixel-based analysis into region-based analysis.
- A hierarchy of segmentations allows dynamic selection of the appropriate level of segmentation detail for each object of interest.
- Behavior of region up and down the segmentation hierarchy also provides analysis clues.

HSEG

HSEG is a hybrid of Hierarchical Step-Wise Optimization* region growing together with spectral clustering – controlled by a *spclust_wght* parameter.

* J. M. Beaulieu and M. Goldberg, "Hierarchy in picture segmentation: A stepwise optimal approach," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 11, no. 2, pp. 150-163, 1989.

RHSEG

A recursive approximation of HSEG, called RHSEG, is much more computationally efficient (especially for *spclust_wght* > 0.0).

- RHSEG recursively subdivides the image data and then recombines the results such that the number of regions handled at any point in the program is restrained.
- The recombination step requires special blending code to avoid processing window artifacts. This special blending code is the subject of a current patent application.

Parallel RHSEG

- Recursive HSEG (RHSEG) facilitates a highly efficient parallel implementation – a full Landsat TM scene (6500x6500 by 6 bands) can be processed in two to eight minutes with 256 2.1 GHz CPUs (Thunderhead Beowulf Cluster).
- Aspects of the parallel implementation of RHSEG have been awarded a patent by the United States Patent and Trademark Office.

HSEGViewer

- The HSEGViewer program provides a convenient, user-friendly, tool for visualizing and interacting with the image segmentation hierarchies produced by the HSEG or RHSEG programs.

HSEG, RHSEG and HSEGViewer

- HSEGViewer and a demo version of RHSEG are available through the Technology Commercialization Office (TCO) web site: http://tco.gsfc.nasa.gov/RHSEG
- More information on HSEG and RHSEG is available through the CISTO web site: http://cisto.gsfc.nasa.gov/TILTON

NASA Disclosures of Technology

- GSC 14,305-1: "Method for Implementation of Recursive Hierarchical Segmentation on Parallel Computers," Feb. 2, 2000.
- GSC 14,328-1: "Method for Recursive Hierarchical Segmentation by Region Growing and Spectral Clustering with a Natural Convergence Criterion," Feb. 28, 2000.
- GSC 14,331-1: "A Region Labeling Tool for use with Hierarchical Segmentation," Feb. 29, 2000.
- GSC 14,448-1: "Method of Artifact Reduction in Approaches to Data Segmentation that employ Data Subdivision and Recombination," Jan. 12, 2001.
- GSC 14,474-1: "Method for Recursive Hierarchical Segmentation combining Greedy and Hierarchical Stepwise Optimal Approaches and Region Splitting," April 19, 2001.

NASA Disclosures of Technology

- GSC 14,681-1: "A Method for Recursive Hierarchical Segmentation which Eliminates Processing Window Artifacts," (revised) Jan. 24, 2003.
- GSC 14,994-1: "A Split-Remerge Method for Eliminating Processing Window Artifacts in Recursive Hierarchical Segmentation," March 9, 2005.
- GSC 14,995-1: "An Innovative Utilization of the Heap Data Structure for Efficient Determination of Best Merges for Hierarchical Segmentation," March 9, 2005.

Patents

- On May 17, 2005, issued patent US 6,895,115 B2 on "Method for Implementation of Recursive Hierarchical Segmentation on Parallel Computers" (based on GSC 14,305-1).
- On May 11, 2004, filed patent application (serial # 10/845,419): "Method and System for Eliminating Processing Window Artifacts in Recursive Grouping Operations" (based on GSC 14,681-1).
- Pending: A continuation in part patent application adding the new techniques from GSC 14,994-1 to the May 11, 2004 patent application.

Licensing

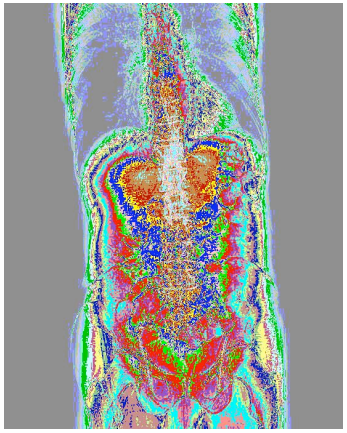
Since November 2002, nonexclusively licensed to Bartron Medical Imaging, LLC, New Haven, CT. Field-of-Use: Use with the Walker Advanced Image Systems (WAIS) and the Biotech Data Image Management Diagnostic System (BDIMD) and any derivative works of the WAIS and BDIMD for in vitro medical and defense applications as it relates to pathogens.

Commercialization of Intelligent Systems Technology: NASA's HSEG and HSEGViewer Commercialized as Bartron Medical Imaging's Med-Seg

James C. Tilton (NASA GSFC/Code 935) and Fitz Walker, Jr. (Bartron Medical Imaging, LLC)

NASA's HSEG and HSEGViewer

- Developed with support from NASA's Intelligent Systems program under NRA2-37143, and from NASA GSFC's Commercial Technology Development program
- HSEG provides hierarchical segmentation of image (e.g., Landsat TM) or image-like data (e.g., IMAGE spacecraft Radio Plasma Imager data)
- Recursive formulation (RHSEG) provides computational efficiency, and has an effective parallel implementation
- HSEGViewer provides a facility for visualizing and interacting with the HSEG results, and allows a user to extract useful segmentation results from the HSEG segmentation hierarchy



CAT Scan **Segmented Scan**

Bartron's Med-Seg applied to body CAT scan

Bartron Medical Imaging's Med-Seg

- Small, minority-owned business founded in 2000
- Product idea: Device to help differentiate difficult-to-see details in medical images to enhance diagnosis
- Attended HSEG presentation at NASA's Medical Imaging Workshop in July 2001
- Realized HSEG could process 16 bit medical image data to reveal information not normally seen with the human eye, which can normally differentiate only 8 to 10 bits
- Worked with NASA to conduct tests to confirm potential
- Licensed HSEG software in November 2002
- UCONN School of Dental Medicine made the first purchase of a Med-Seg device in July 2003
- In April 2004, UCONN reports their Med-Seg based approach appears to provide dramatic improvement over other approaches for diagnosing osteoporosis.

Advantages and Potential of Med-Seg

- Meg-Seg provides enhancement of diagnosis power for a wide range of medical images
- Bartron's 64 CPU parallel computer cluster provides HSEG results quickly, even for large images
- HSEGViewer provides the medical analyst ultimate control over selection of segmentation results
- Bartron currently seeking FDA approval for Med-Seg
- Application to MRIs and CAT scans currently under study
- Bartron is exploring other possible uses with the Dept. of Defense, Dept. of Agriculture and the Indian Health Service

NASA Projects

- Intelligent Systems Program, NRA2-37143: "Knowledge Discovery and Data Mining based on Hierarchical Segmentation of Image Data," May 2001 – April 2004.
- GSFC Mission Infusion Task: "Applying Intelligent System Technology to Extract and Understand Radio Imaging Data," October 2003 – September 2004.
- CRADA between NASA and Bartron Medical Imaging, LLC: "Extension of Recursive Hierarchical Segmentation (RHSEG) from Two- to Three-Dimensional Analysis," September 2005 – October 2006.
- Pending: NASA ROSES NRA, Land Cover/Land Use Change Element: "Improved Monitoring of Change through Utilization of Hierarchical Segmentation."

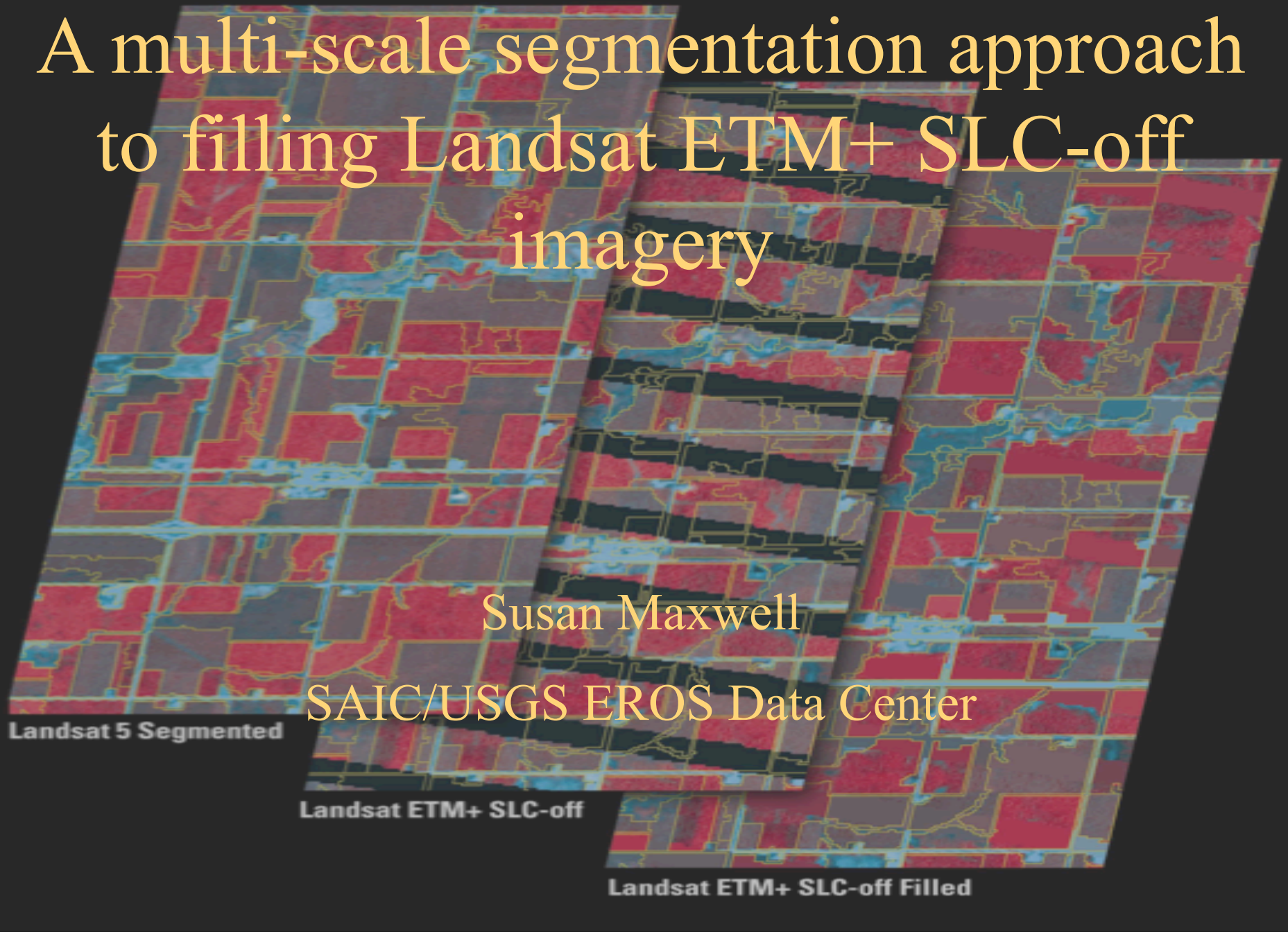
Other Potential Projects

- Jay Pearlman, Dartmouth University, "Three Dimensional Analysis of Serially Acquired 2D Data" (analysis of 3D data in order to characterize the effects of early cancers on microvascular changes).
- John Kolasinski, Code 565, NASA GSFC: "Nondestructive testing of fibers through analysis of X-Ray images."
- Susan Maxwell, SAIC/USGS EROS Data Center: "A multi-scale segmentation approach to filling Landsat ETM+ SLC-off imagery."
- …

A multi-scale segmentation approach to filling Landsat ETM+ SLC-off imagery

Susan Maxwell

SAIC/USGS EROS Data Center



Summary

- Hierarchical Segmentation (HSEG) developed as a hybrid of Hierarchical Step-Wise Optimization (region growing) and spectral clustering.
- Recursive HSEG (RHSEG) approximation is more computationally efficient, and has a straightforward and fast parallel implementation.
- The HSEGViewer program provides a convenient, user-friendly, tool for visualizing and interacting with the image segmentation hierarchies produced by the HSEG or RHSEG programs.
- Aspects of RHSEG's parallel implementation are patented, and a patent is being applied for RHSEG processing window artifact elimination strategies.
- RHSEG and HSEGViewer have been licensed to Bartron Medical Imaging, LLC for a commercial medical image analysis product.
- A CRADA project between NASA and Bartron project is underway for the development of an extension to three-dimensional analysis.
- Other potential applications to earth science, non-destructive testing, and medical image analysis are being pursued.

HSEG, RHSEG and HSEGViewer

- HSEGViewer and a demo version of RHSEG are available through the Technology Commercialization Office (TCO) web site: http://tco.gsfc.nasa.gov/RHSEG
- More information on HSEG and RHSEG is available through the CISTO web site: http://cisto.gsfc.nasa.gov/TILTON